Texas Instruments
Registration
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System

TIRIS Technology by Texas Instruments™

Digital Signature
23 mm Glass Transponder

RI-TRP-BRHP

Reference Manual

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This is the first edition of this manual, it describes the following transponder:

RI-TRP- BRHP

This Reference Manual is for customers who wish to use the TIRIS Digital Signature 23 mm Glass Transponder in Radio Frequency Identification (RFID) installations. The manual includes technical information concerning the function, technical specifications, application and environmental related data.

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1. Introduction

The TIRIS Digital Signature Glass Transponder can be used for a variety of applications, such as automotive security systems and other electronic locks. It is one product in the TIRIS low frequency RFID product line.

Electromagnetic signals are used to:

- power the passive (batteryless) device
- exchange data between the reader unit and the device, or
- program the device with new data.

The basic principle is described in Figure 1. The control unit sends any random number of predetermined length to the transponder, which is then scrambled in a unique way such that the control unit can authenticate the response as being *only* from a valid transponder. The transponder scrambles the random number in a unique way, based upon an encryption key which is known only by the control unit and the valid transponder.

The 23 mm Glass Transponder comprises a ferrite core antenna, two capacitors and the integrated circuit (Figure 2). The antenna inductance and a capacitor form a high quality resonant circuit. The components are enclosed in a plastic housing.

The transponder has an 88 bit non-volatile memory for storage of an 8 bit password, an 8 bit identification, a 24 bit serial number, an 8 bit manufacturer code and the 40 bit encryption key.

The complete system comprises an interrogator (RF module and control unit), an antenna (usually mounted around the car keylock cylinder), and the transponder (in the key) as shown in figure 1.

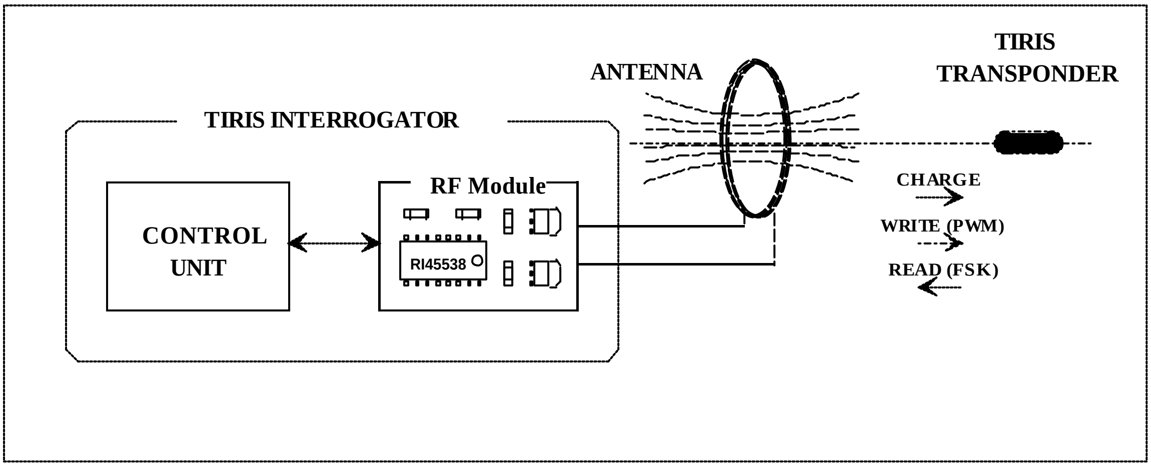


Figure 1: System Configuration Showing the Reader, Antenna and Transponder

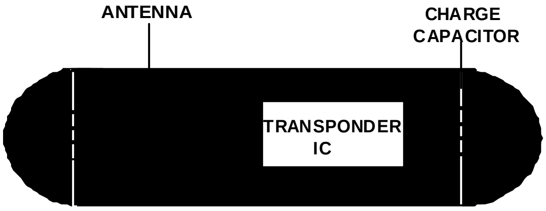


Figure 2: Block Diagram of the TIRIS 23 mm Glass DST

2. Transponder Packaging

The dimensions of the transponder are given in Figure 3.

The 23 mm shape offers several advantages:

1. The transponder is hermetically sealed.
2. The transponder is robustly constructed to withstand vibration (IEC68-2-6) and shock (IEC68-2-6).
3. For Applications where read range is not the most critical point the transponder can be mounted or used in such a way that the orientation is not controlled.

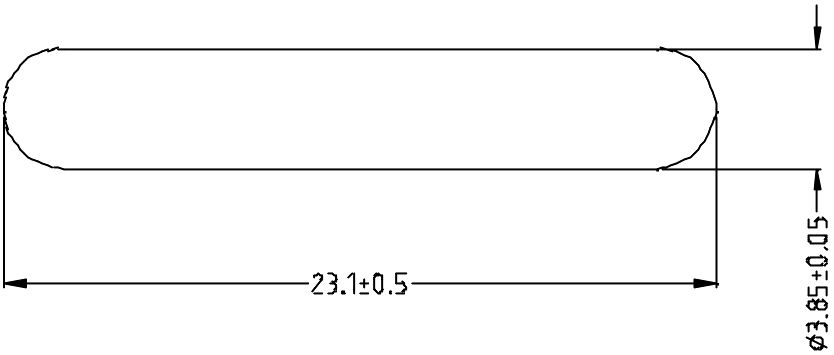


Figure 3: Dimensions of the TIRIS 23 mm Glass DST (in mm)

3. References

[1] TIRIS RF Module IC Reference Manual Rev. 1.4, 05/31/94

[2] Application Note ‘RF Module with IC RI45538’, Rev. 2.0, 12/12/94

[3] Digital Signature Transponder Algorithm and Software Requirements (NDA Required)
Document number 24-09-05-012

[4] Digital Signature Transponder Sequence Control Specification (NDA Required)
Document number 24-06-05-005

4. Product Codes

There are currently three products in the Digital Signature Transponder range, these are:

DST Wedge Transponder:	RI-TRP-B9WK
DST Block Transponder:	RI-TRP-A9WK
DST Glass Transponder:	RI-TRP-BRHP

5. System Description and Method of Operation

5.1 General

The method of operation requires the interrogator to send a charge-up signal together with a 40-bit interrogation signal (challenge). The transponder then encrypts this 40-bit challenge and returns to the interrogator a unique 24-bit response (signature) together with the transponder's individual 24-bit serial number. The 24-bit response is a function of both the 40-bit challenge and the 40-bit encryption key that was written into the transponder by the interrogator during the initialization phase. This encryption key is held in the memory of the reader and the transponder.

Programming can be made even more secure by the use of the password feature. If the password feature is enabled, the interrogator must first send the correct password to the transponder (together with the charge-up) before the transponder can be programmed. However, use of the password for read or encryption functions is optional, even if the password feature is enabled.

5.2 Interrogator

The Interrogator consists of an RF module and a control unit. The RF module [2], built using a TIRIS RF Module IC RI45538 [1] is partitioned in the transmit and receive paths, both of which are connected to the same antenna circuit (see figure 4).

The transmitter is used for contactless supply of the transponder (charge phase), for transmission of data to the transponder (write phase) using pulse width modulation (PWM) and to program and lock the transponder EEPROM (program phase). It is controlled by the active low transmit control input (TXCT-).

The receiver demodulates the transponder response signal (read phase), which is modulated using Frequency Shift Keying (FSK). It provides a receive data output (RXDT) and a receive clock output (RXCK).

5.3 Method of Operation

Before the transponder can perform a proper encryption of a challenge its EEPROM must be initialized (programmed) by the interrogator (reader). This means that the interrogator has to write into the transponder:

- the 8-bit password (if required),
- the 8-bit identification (optional), and
- the 40-bit encryption key.

During normal use (encryption mode), a 40-bit random number (challenge) is sent to the transponder. This random number is encrypted by the transponder using the encryption key. The resulting 24-bit response (signature) is returned to the interrogator together with the 24-bit serial number for verification and authentication.

The Password in the EEPROM can be programmed and locked by the interrogator. If enabled, the program and lock functions must be used in a selective addressing mode (password protected mode). The other function of read and encryption allow for optional use of the password if it has been enabled.

Because the transponder is normally used together with RI-RFM-006A connected to a low Q keylock antenna, the write speed is increased, compared to standard TIRIS transponders.

5.3.1 Initialization

When the transponder is delivered, parts of the EEPROM are unlocked and must be programmed to the desired password, identification number and encryption key. The write data formats are similar to the data formats used with the standard TIRIS read/write transponders. Data transfer to the transponder is protected by a Cyclic Redundancy Check (CRC), refer to section 5.4.2. For this purpose a 16-bit CRC-generator is used to generate the Block Check Character (BCC), which is sent along with the data when programming and locking the transponder. It utilizes the CCITT algorithm but uses a start value which is different than that used by other TIRIS transponders.

During the subsequent read phase (which is also protected by cyclic redundancy check), the newly programmed password and/or identification number is returned to the interrogator, but not the encryption key. This means that once the encryption key has been programmed, the only method to check if the encryption key has been programmed correctly is by using the encryption mode with a test pattern. A successful programming (initialization) is indicated by a status byte (called the read address) that is returned as part of the read data format, refer to section 6.3.1.

Once the encryption key has been successfully programmed, it can be “locked”. The various modes of Locking, Programming, and Encryption are controlled via a command (called the write address) that is sent to the transponder immediately after the charge phase, refer to section 6.2.1.

When the write data format for the encryption lock function, the identification lock function and/or the password lock function is sent to the transponder, the corresponding lock bit is set. Successful locking is indicated by the status field of the read address, which is sent by the transponder in response to a lock mode command. ***Locking prevents the EEPROM from being reprogrammed in future. Once set, the lock bit cannot be reset.*** Any attempt to reprogram the EEPROM is denied if the lock bit is set.

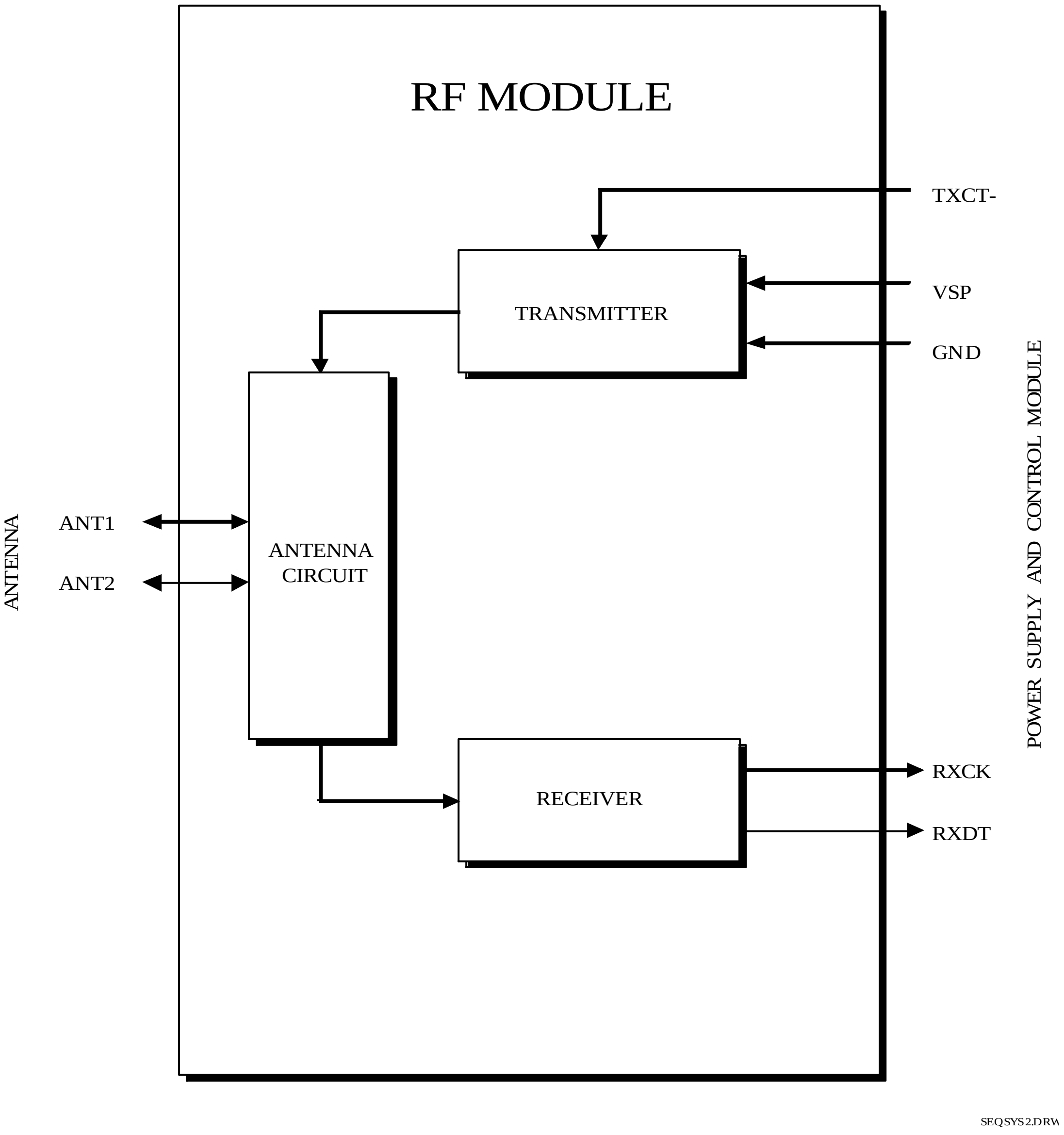


Figure 4: RF Module - Block Schematic

5.3.2 Encryption Mode

In the encryption mode the interrogator sends (writes) the encryption command in the write address followed by a 40-bit random number (challenge) to the transponder. The challenge is shifted into the encryption logic, which is also initialized with the 40-bit encryption key stored in EEPROM. When the challenge has been completely received, a block cipher algorithm is executed using both the challenge and the encryption key. If fewer or more bits are received, a discharge is executed in the subsequent read phase (no response).

Once it detects the end of the encryption phase, the transponder responds by sending the 24 bit serial number stored in the EEPROM and a 24 bit response (signature) that was generated by the block cipher algorithm.

5.3.3 Password Protection

If a password has been programmed into the transponder’s EEPROM, the program and lock modes (functions) must be selectively addressed (using the password). These functions are only executed if the password sent to the transponder matches the password stored in the transponder. All encryption and read modes (functions) will work with or without selective addressing (using the password). The password can be programmed and locked by the user.

5.4 Transponder

5.4.1 Memory

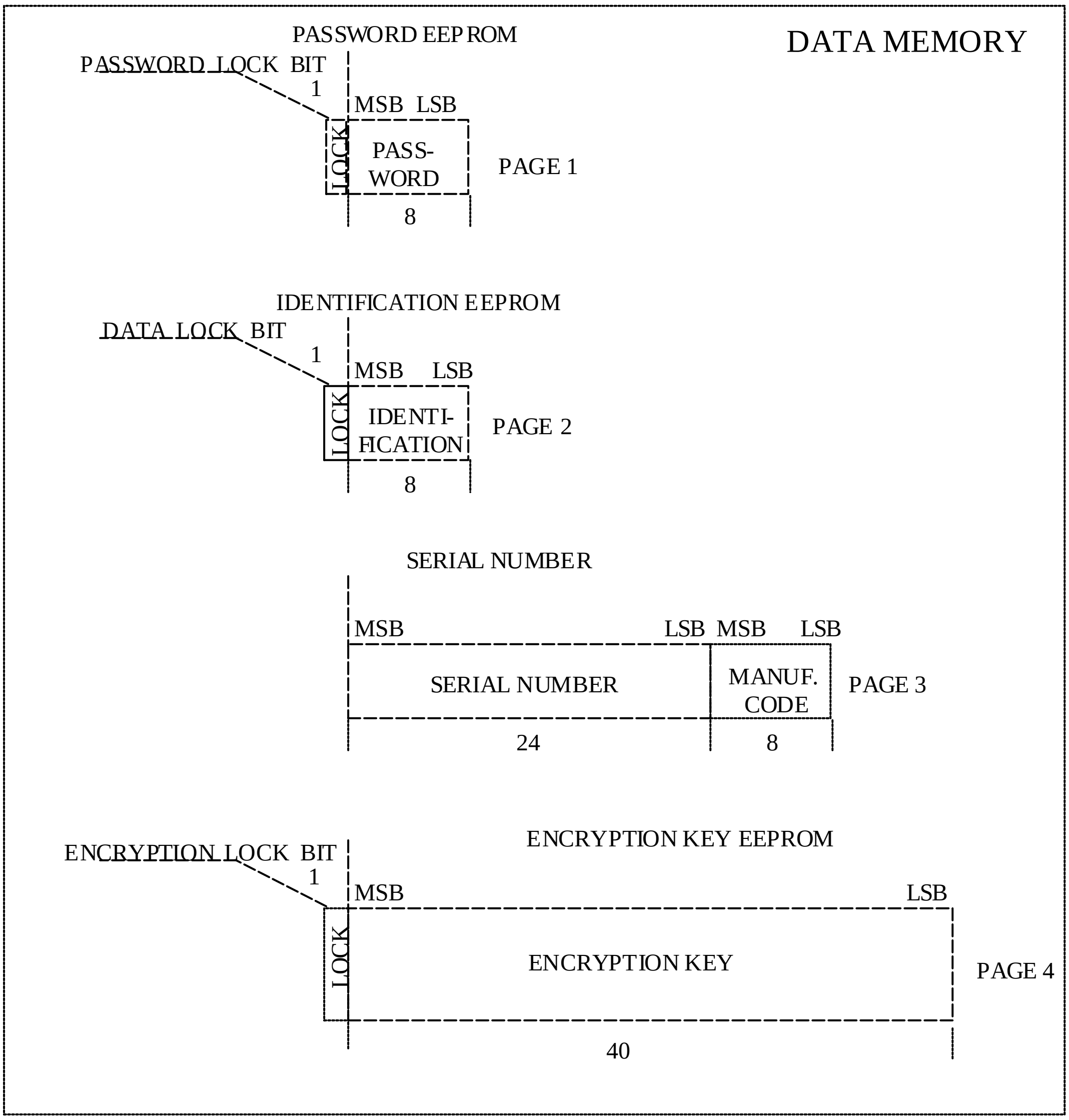
The memory in the transponder comprises four pages as shown in figure 5. Each page has a separate lock bit, which is either programmable by the user or set during manufacture. The data is accessed via serial shift registers during write and read functions.

5.4.1.1 Password EEPROM (Page 1)

The password EEPROM contains 8 password bits and a password lock bit. The password is used for selective programming, selective locking, selective reading and selective encryption. The password EEPROM is programmable by the user (as long as the password lock bit is not set) via the program page 1 function. The password lock bit can be set by the user, using the lock page 1 command (write address). Once set, the password lock bit cannot be reset.

To activate the password feature, the user must write a password other than ‘11111111’ into page 1. If the password in the EEPROM is not ‘11111111’, it will be compared with the password received from the interrogator (write phase). If the password is ‘11111111’ (default) no comparison is performed.

When page 1,2 or 3 is addressed the password (page 1) is returned in a consecutive read phase together with the identification (page2), manufacturer code and serial number (page 3). The status of page 1 lock bit is returned only when page 1 is addressed.



SEQEEP1B.DRW

Figure 5: Memory Organization

5.4.1.2 Identification EEPROM (Page 2)

The identification EEPROM contains 8 identification bits and an identification lock bit. The identification is typically used for numbering of the keys within an application (for example: the key number per car). The identification EEPROM is programmable by the user (as long as the identification lock bit is not set) with program page 2 function. The identification lock bit can be set by the user, using the lock page 2 command (write address). Once set the identification lock bit cannot be reset.

The contents of the identification EEPROM (read data) and the status (locked or unlocked) are returned during the read phase (read address), together with the password (page 1), the manufacturer code and the serial number (page 3) if page 1, 2 or 3 are addressed. The status of the lock bit is returned when page 2 is addressed.

5.4.1.3 Serial Number (Page 3)

The serial number memory portion contains an 8 bit manufacturer code and a 24-bit serial number. The manufacturer code is used for distinguishing transponders sold to a specific manufacturer, so that the transponder can only be used for applications for that manufacturer. The serial number is used for numbering the transponder within an application.

The manufacturer code is programmed by TI, together with the serial number. The manufacturer code and serial number cannot be changed.

The contents of the manufacturer code together with the serial number is returned when page 1, 2 or 3 are addressed, the status (locked) is returned when page 3 is addressed.

5.4.1.4 Encryption Key EEPROM (Page 4)

The encryption key EEPROM contains 40 encryption key bits and an encryption lock bit. The encryption key is used in the encryption logic to scramble the received random number (challenge) in order to generate the encrypted response (signature).

The encryption EEPROM must be programmed by the user during the initialization phase (program page 4). After it has been programmed, the encryption lock bit can then be set. The encryption lock bit can be set by the user using the lock page 4 command (write address). Once set the encryption lock bit cannot be reset.

The content of the encryption EEPROM is never returned during read phase. To find out if the encryption key is correct or not, a challenge must be sent to the transponder and the response (signature) checked. The status of the encryption lock bit (locked or unlocked) is returned during the read phase (read address), if the general read page 4 (encryption mode), selective read page 4 (selective encryption mode), the program page 4 or the lock page 4 function is initiated.

5.4.2 Cyclic Redundancy Check Generator

A Cyclic Redundancy Check (CRC) Generator is used in the transponder during receipt and transmission of data to generate a 16-Bit Block Check Character (BCC), applying the CRC-CCITT algorithm (see Figure 6).

The CRC-Generator consists of 16 shift register cells with 3 exclusive OR gates. One exclusive OR gate combines the input of the CRC-Generator with the output of the shift register (LSB) and feeds back to the input of the shift register. Two of the exclusive OR gates combine certain cell outputs with the output of the first exclusive OR gate and feed into the next cell input.

The CRC Generator is initialized with a secret Start Value [4] (LOAD signal).

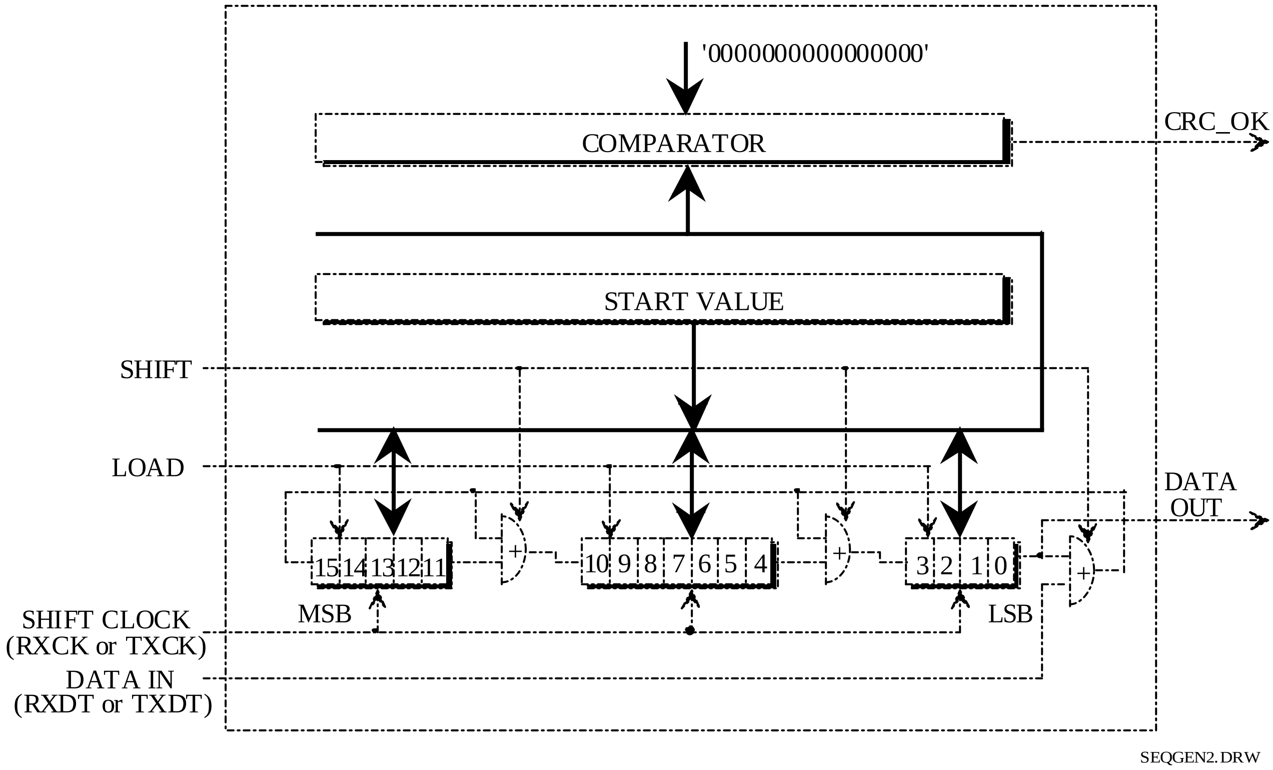


Figure 6: Block Schematic of CRC Generator

The CRC generation is started with the first shifted bit, received during write phase RXCK, RXDT. After reception of program or lock command and the additional bits, including the write frame BCC, the CRC Generator content is compared to 0000_{HEX} (CRC_OK).

During read function CRC generation is started after transmission of the start byte. After the read data, the serial number, then the signature followed by the read address byte, the CRC Generator content is shifted , using the CRC generator as a normal shift register (SHIFT signal).

From a mathematics point of view, the data, which are serially shifted through the CRC Generator with LSB first, are multiplied by 16 and divided by the CRC-CCITT generator polynomial:
$P(X) = X^{16}+X^{12}+X^{5}+1$. The remainder from this division is the Read Frame Block Check Character (Read Frame BCC).

The interrogator control unit has to use the same algorithm to generate the Write Frame BCC and to check the Read Frame BCC received from the transponder. The response is checked by shifting the Read Frame BCC through the CRC generator in addition to the received data; the content of the CRC generator must be zero after this action.

Typically the CRC generator is realized in the control unit by means of software and not hardware. The algorithm can be handled on a bit-by-bit basis (see figure 7) or by using look-up tables.

5.4.3 Encryption Algorithm

The encryption algorithm is defined in detail in a separate description [3]. The time provided for encryption (encryption time, t_{enc}) must be long enough to allow the encryption logic to completely finish the encryption process, otherwise the transponder will not respond. Because of the higher power consumption during encryption process, the supply voltage of the transponder can drop if the transponder is too far from the antenna. Therefore the encryption time allowed is typically twice the actual encryption execution time (t_{encx} , see Section 10.2 “Recommended Operating Conditions”).

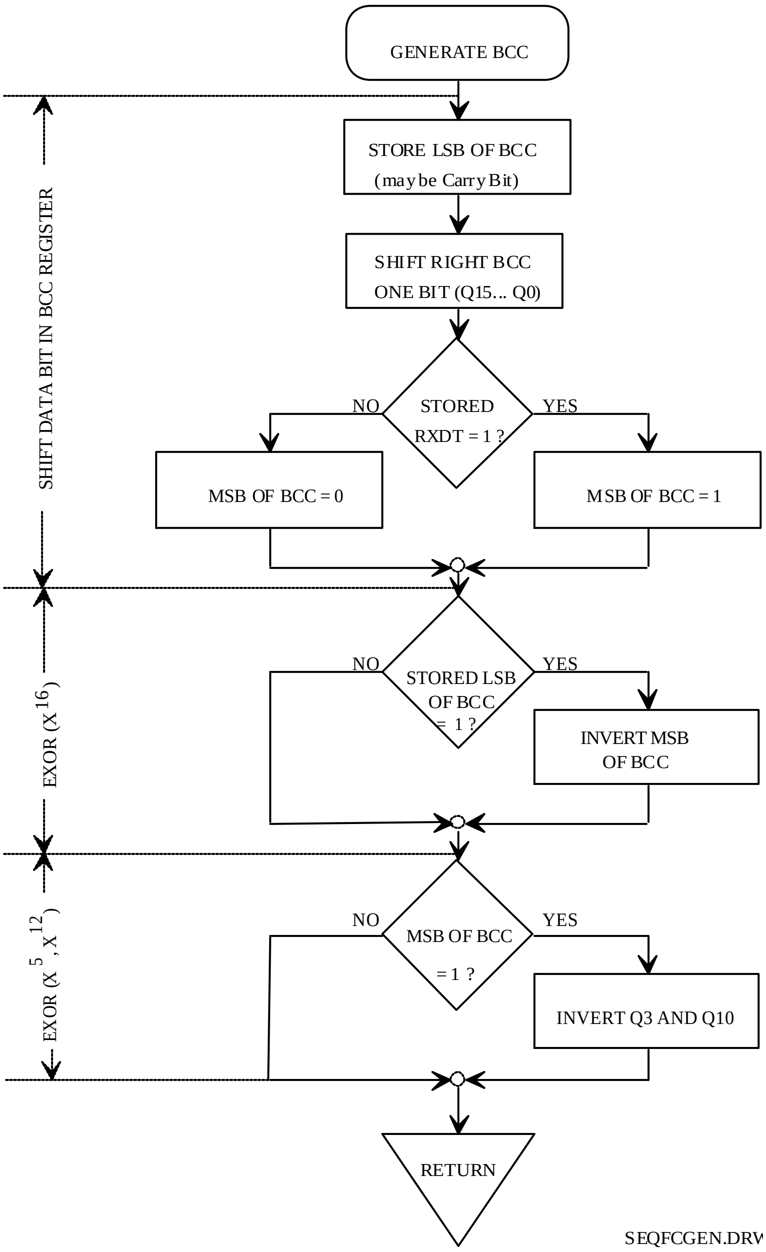


Figure 7: Subroutine ‘Generate Block Check Character’

6. Function

The TIRIS FM System uses a sequential function principle separating the transponder powering (charge) and transponder data transmission mode. The advantages of the sequential mode are described in Section 7.1 "Basic System Data".

6.1 Charge

During the charge (or powering phase) of between 15 and 50 ms the interrogator generates an electromagnetic field using a frequency of 134.2 kHz. The resonant circuit of the transponder is energized and the induced voltage is rectified by the integrated circuit to charge the capacitor. The transponder detects the end of the RF signals and transmits its data using Frequency Shift Keying (FSK), utilizing the energy stored in the capacitor.

6.2 Write

The write function (see Figure 8) is used to transfer commands, addresses and data to the transponder in order to activate certain functions. Writing is started after the charge phase, it is achieved by switching the RF Module’s transmitter off and on the of the according to the data bits.

The duration of the transmitter deactivation , detected by the transponder t_{off}, defines if it is a low bit or a high bit. During a high bit the transmitter is deactivated for toffH and activated afterwards for tonH. During a low bit the transmitter is deactivated for toffL and activated afterwards for tonL. The duration of the deactivation detected by the transponder, must be greater than the high detection threshold time (tHdet). During read page and selective read function the write phase is followed by a read phase (tRD).

The write bit duration (tbitL, tbitH) consists of the transmitter deactivation time (toffH, toffL) and a transmitter activation time (tonH, tonL), which is necessary to recover the energy lost during toff. The duration of a write bit deactivation defines whether it is a low bit or a high bit.

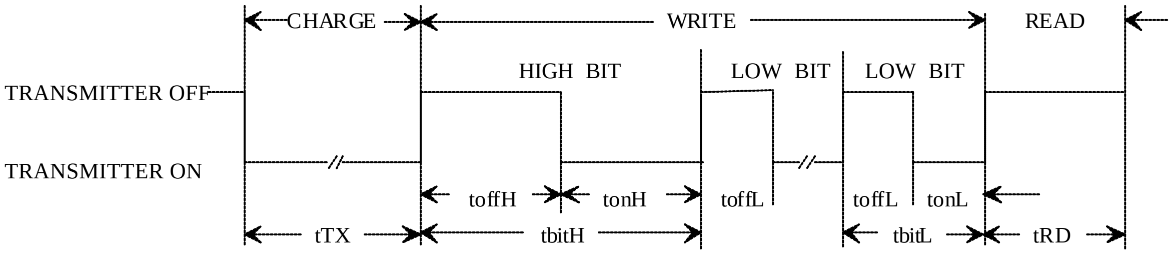
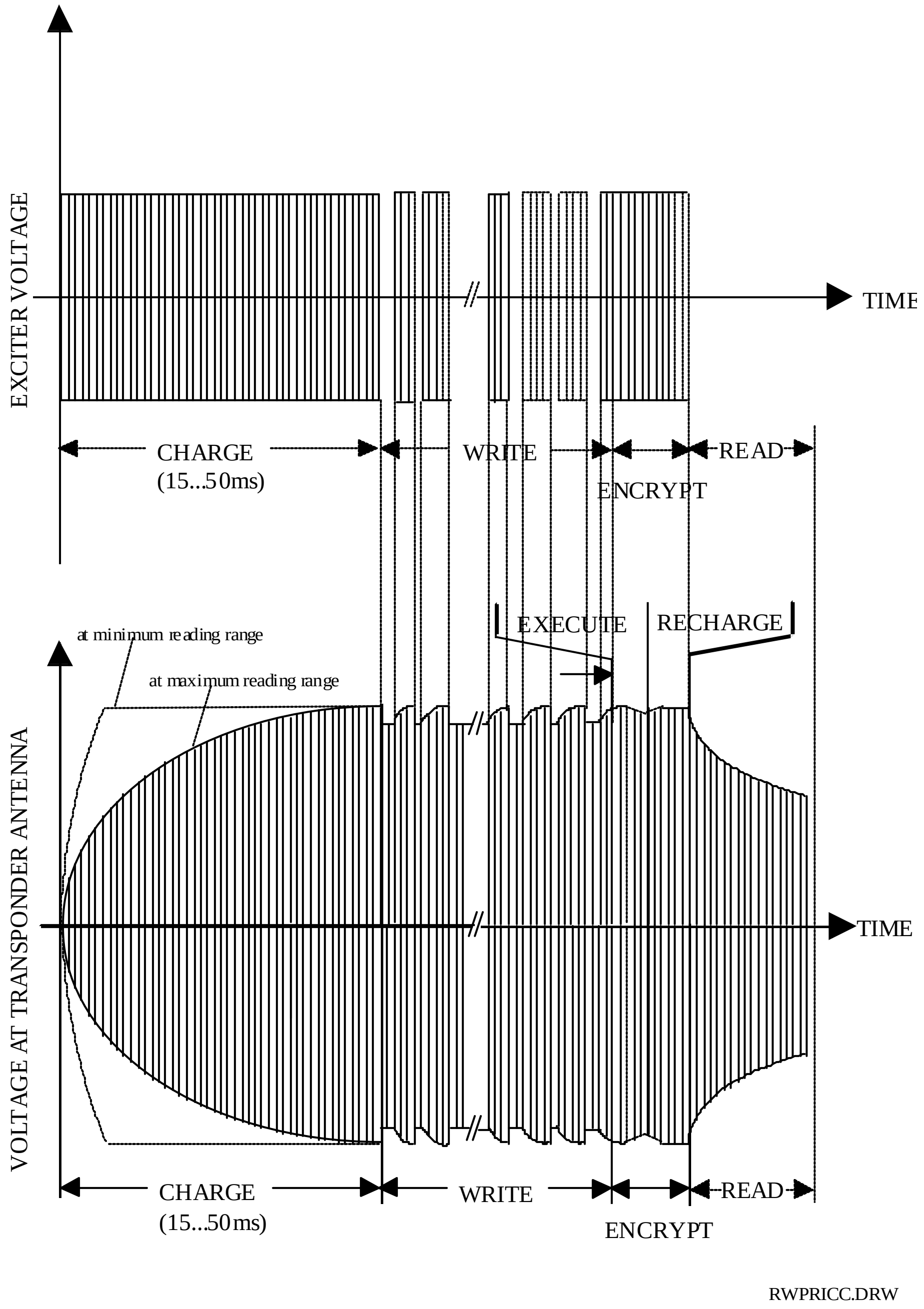


Figure 8: Timing of Write function



Charge:	Continuous RF Module transmitter output signal
Write:	Pulse width modulation of the RF module transmitter output signal
Program:	Continuous RF module transmitter output signal
Read:	Frequency Shift Keying of the transponder resonant circuit oscillation

Figure 9: Voltage at the Transponder and Exciter (Reader) Coils during Typical Function

6.2.1 Write Data Formats

The memory of the transponder is structured in multiple pages. To read a certain page (general read), to program (program page) or to lock data in a certain page (lock page) or to use the encryption mode, the user has to send (write) a write address and data to the transponder.

The Write Address byte consists of a 2-bit command field and a 6-bit page field. The command field, which is transmitted first (LSB first), determines the function to be executed. The page field defines the affected page.

WRITE ADDRESS
MSB LSB
P P P P P P C C
| |

	PAGE	COMMAND	
	MSB LSB	MSB LSB	
Page 1	000001	00	General Read/ Encryption Mode
Page 2	000010	01	Program Page
Page 3	000011	10	Lock Page
Page 4	000100	11	Selective Read Page/ Selective Encryption Mode

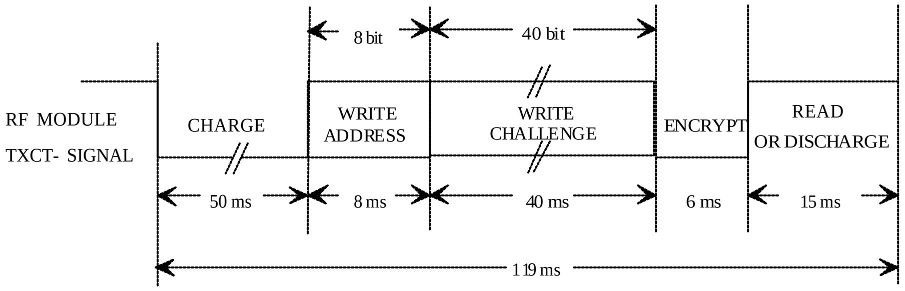


Figure 10: Write Data Format of Encryption Mode

6.3 Read

The Read phase starts with each deactivation of the transmitter (TXCT-), which is detected by the transponder, because the transponder resonant circuit RF amplitude drops. The transponder starts with transmission of 16 Pre-bits. During this phase the resonant circuit resonates with the low bit transmit frequency (f_L). During transmission of the read data or response, the resonant circuit frequency is shifted between the low bit transmit frequency (f_L) and the high bit transmit frequency (f_H).

The typical data low bit frequency is 134.3 kHz, the typical data high bit frequency is 122.9 kHz. The low and high bits have different durations, because each bit takes 16 RF cycles to transmit. The high bit has a typical duration of 130.2 µs, the low bit of 119.1 µs. Figure 11 shows FM principle used. Regardless of the number of low and high bits, the transponder response duration is always less than 15 ms.

Data encoding is done in NRZ mode (Non Return to Zero). The clock is derived from the RF carrier by a divide-by-16 function.

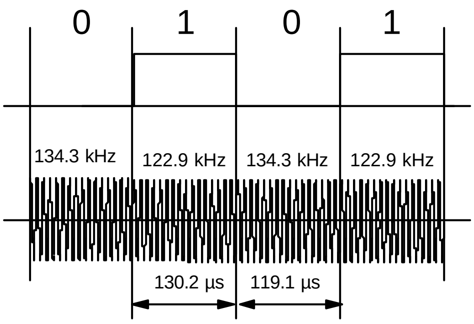


Figure 11: FM Principle Used for the Read Function of TIRIS Transponders

After a charge phase only (without write phase), the transponder discharges its capacitor at the end of the Pre-bit phase, which results in no response. If a valid function was detected during the write phase, the complete read data format is transmitted. The content of the read data format depends on the previously executed function.

When the last bit has been sent, the capacitor is discharged. During discharge no charge-up is possible.

A sufficiently long read time (tRD) must be provided to ensure that the complete read data format can be received (allowing also for possible transponder response frequency deviations).

6.3.1. Read Data Formats

During the read phase, the transponder transmits a read data format which consists of 96 bits (see figures 12 and 13). All parts of the Read Data Format are transmitted with LSB first.

The Data Format starts with 16 Pre-bits that are all zero (0000 $_{\text{HEX}}$), followed by the start byte 01111110$_{\text{BIN}}$ (7E$_{\text{HEX}}$). If pages 1, 2 or 3 are addressed, the password (8 bit), identification (8 bit), manufacturer code (8 bit) and the serial number (24 bit) are transmitted. If page 4 is addressed, the serial number and the signature are transmitted (encryption mode):

Page Addressed	Read Data Format
Page 1	Password + Identification + Manufacturer code + Serial Number
Page 2	Password + Identification + Manufacturer code + Serial Number
Page 3	Password + Identification + Manufacturer code + Serial Number
Page 4	Serial Number + Signature

The content of the subsequently sent read address depends on the function executed. Finally, the 16-bit Read Frame BCC is transmitted. The transponder ends the read data format during bit 97, while discharging the charge capacitor.

The read address consists of a 2-bit status field (transmitted first), used for status information only and a 6-bit page field, which is used for page information and status extension. If the page field is zero, the status field has a different meaning:

READ ADDRESS

MSB LSB

P P P P P P S S

| |

PAGE STATUS

	MSB LSB	MSB LSB	
Page 1	000001	00	Read unlocked page
Page 2	000010	01	Programming done
Page 3	000011	10	Read locked page
Page 4	000100		
	000000	00	Read unlocked Page, locking not correctly executed
	000000	01	Programming done, but possibly not reliable
	000000	10	Read locked Page, but locking possibly not reliable

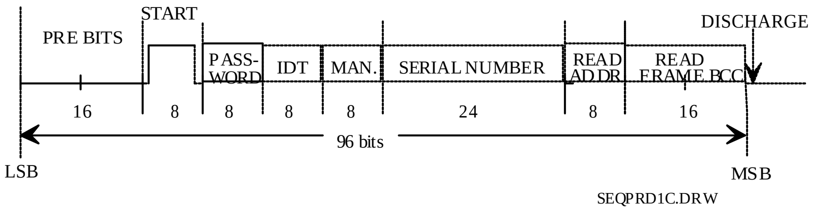


Figure 12: Read Data Format during Program and Lock Function

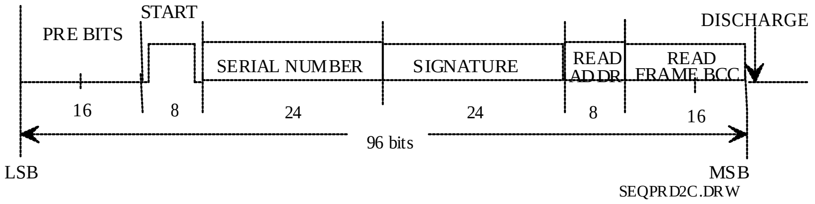


Figure 13: Read Data Format during Encryption Mode

7. Characteristics of the TIRIS FM System

7.1 Basic System Data

The TIRIS FM system multiplexes the power and read functions avoiding compromises. This results in the following characteristics and options:

a) Individual optimization of the power and read functions by the system designer.

b) Variation of powering time by S/W to trade-off speed/current consumption with other parameters

c) Absence of the high powering signal during the data reception phase

d) Data transmission by an active oscillator. This is associated with a high signal strength level and a high transponder efficiency.

e) NRZ modulation encoding for high data speed and low transmission bandwidth.

7.2 Reader and System Design Impact

* Ease of receiver and power function design and the optimization of performance due to sequential power/read functions.

* Low field strength for transponder charge, resulting in lower cost of the power function.

7.3 System Performance and Functional Reliability Impact

* Inherent EMI robustness and high system Signal/Noise ratio because:

A. The transponder emits 6..20 dB higher data signal (compared to competitive systems).

B. The powering phase is noise immune and the data transmission phase duration is typically <15 ms.

C. FSK and NRZ allow a high data rate (typically 9 kbit/s).

D. Modulation is direct carrier FSK which has inherent AM noise suppression.

* Low reader power dissipation because of low charge field strength.

* Low power consumption due to pulsed operation (=low peak power x low duty cycle).

* Data telegram transmission is secured by 16 bit CRC-CCITT error detection protocol.

* The receive time is short, because the transponder protocol always starts at the beginning of the data stream. Therefore read repetitions are not necessary.

7.4 Other Quality Factors of the TIRIS Pulsed FM System

* High and consistent transponder product quality and performance.

* The direct FSK provides enhanced separation and better position-selective reading of adjacent transponders compared to AM systems.

* Product migration path concept from RO to R/W to Password protected, Multipage, and Digital Signature transponders. The reader or system can be changed by S/W change only.

8. EMI/EMC Performance

8.1 General

For any given RF-ID system, the EMI/EMC performance is determined by three factors:

1. The reader design and the resulting noise immunity performance
2. The signal strength of the transponder and Signal/Noise ratio at the receiver input
3. The transponder immunity to EM fields:
   - The most critical EMI factor or component in a system is the reader immunity.
   - A high transponder data signal facilitates reader design through the higher Signal/Noise ratio.
   - The least critical component is the transponder. Immunity levels are generally very high.

All EMI sources can be classified into three different categories:

a. Broad band "industrial" noise of sporadic or continuous nature
b. Discrete radio frequency signals unmodulated or FM /FSK modulated
c. Discrete radio frequency signals which are AM or ASK modulated.

8.2 The Automotive Environment and Factors

In an automotive environment all noise types are present and potentially cause EMI problems.

Especially the increased application of electronics and communication systems in cars employing digital and ASK type modulation techniques can produce and emit high field strength levels.

The highest energy noise sources are in the low frequency part of the spectrum at frequencies from a few cycles up to a few kHz. The sources are actuators, solenoid switching, ignition, motors, control circuitry and so on. They pollute the car environment, either by direct emission, or by induction, or by conducted radiation.

Above 10 kHz, the noise levels decay quickly at a rate of 20...40 dB/octave. RFID systems emitting and receiving data signals at these or higher frequencies are less affected by EMI.

8.3 TIRIS FM Transponder and System Performance

EMI measurement procedures which are most currently cited (for example the DIN 40839/part4) are inappropriate to:

a. determine a realistic RF-ID *system behaviour* for an automotive environment
b. determine the EMI performance and threshold of transponder
c. test systems at worst case (low frequency) conditions.

However the TIRIS transponder meets and exceeds the DIN40839/part4.

The TIRIS system performance using reader and 23 mm Glass transponder is shown in figures 14, 15 and 16.

Figure 14 shows the system immunity over a spectrum of 6 decades. At the most critical Radio Short Wave Broadcast frequencies 400 V/m were encountered.

Figure 15 highlights the system performance simulating in-car RF communication conditions.

Figure 16 shows the performance (reading range) under induced broad band noise (white noise) conditions.

Pulsed FM EMI System Performance

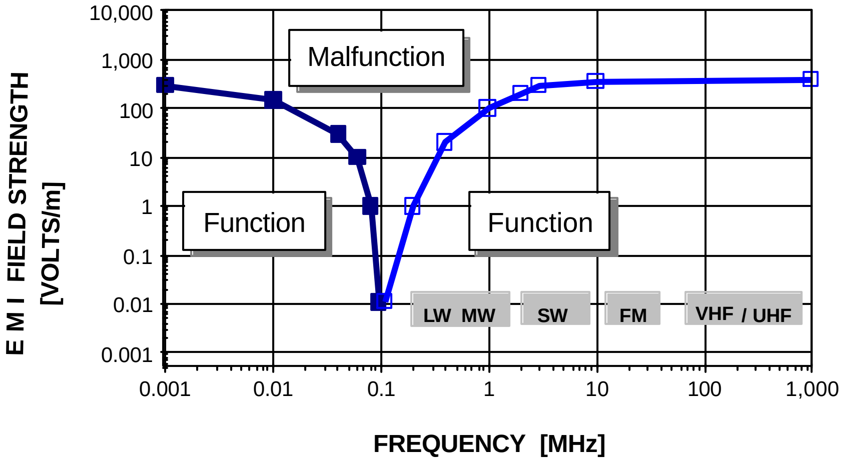


Figure 14: EMI Performance Test of the TIRIS System.

The graph shows the EM Immunity level in V/m as function of the frequency range from 1 kHz to 1000 MHz. Measurement condition: minimum 90% read probability at maximum read range. Using a standard TIRIS reader.

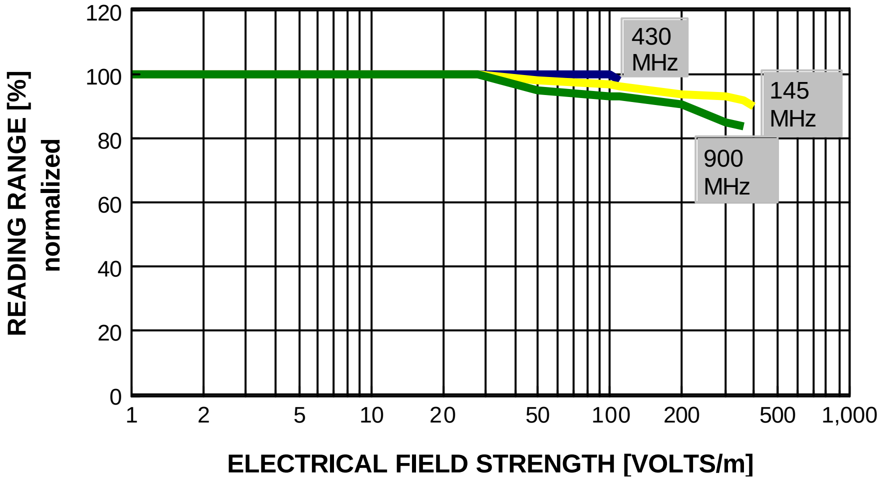


Figure 15: EMI performance at commonly used radio communication frequencies in automotive environment.

White noise performance of TIRIS

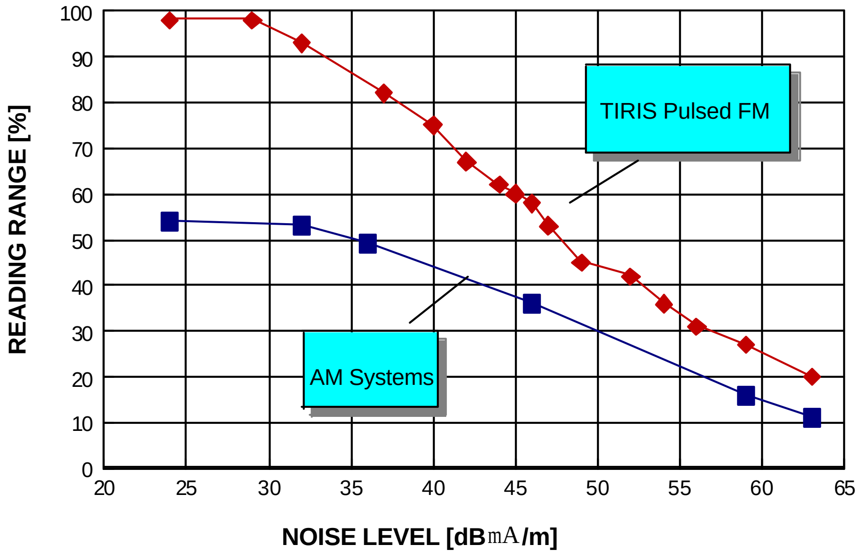


Figure 16: Reading range under broad band noise (white noise) conditions

9. Measurement Set-Ups

This Section describes typical measurement set-ups to determine transponder relevant data like: resonant frequency, bandwidth, quality factor, powering field strength and transponder signal field strength as listed in Section 10.2 "Recommended Operating Conditions".

9.1 Measurement Set-Up: Resonance frequency, bandwidth, quality factor of transponder

This test set-up is suitable for resonant frequency (f_{res}) measurements as well as the determination of the -3dB bandwidth (Δf) of the transponder. The quality factor Q of the transponder resonance circuit can be calculated with equation (1):

$$Q = \frac{f_{res}}{\Delta f} \qquad (1)$$

The wires of the pick-up coil should be very thin to avoid influence on the measurement results (for example: by damping). The choice of a 1 MΩ input resistor at the spectrum analyzer is recommended. Figure 17 shows the test set-up. The relation between pick-up coil voltage and frequency is shown in Figure 18.

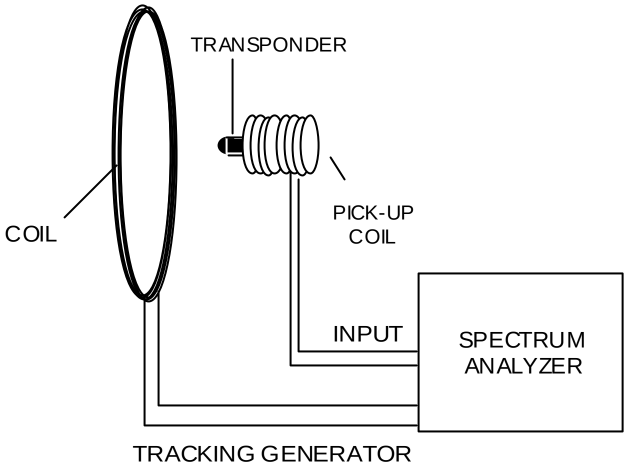


Figure 17: Measurement set-up for the determination of transponder resonance frequency, bandwidth and quality factor

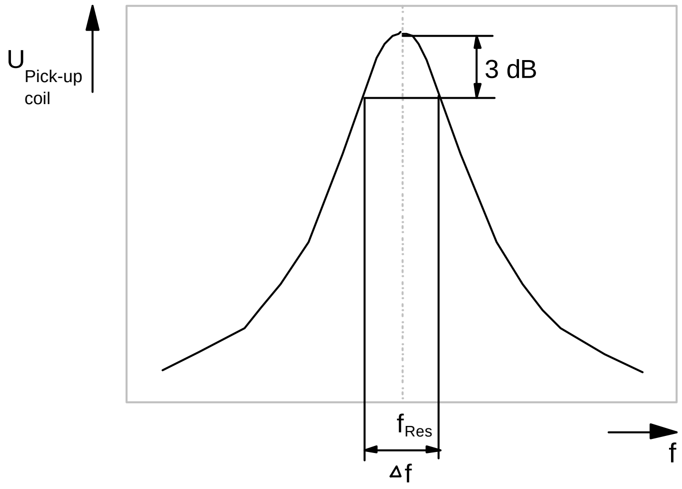


Figure 18: Determination of the resonance frequency and -3dB bandwidth by monitoring the pick-up coil voltage

9.2 Measurement Set-Up: Powering Field Strength

The following set-up is used to determine the minimum required powering field strength.

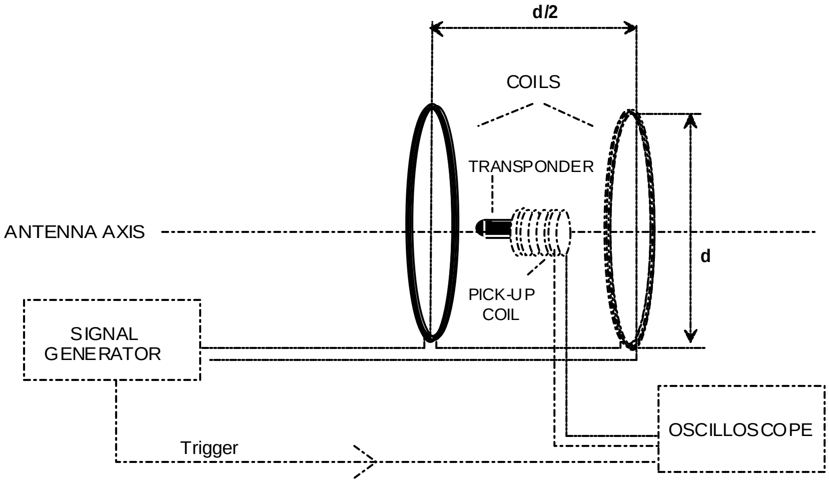


Figure 19: Test set-up for powering field strength determination

The field between both serial connected coils is homogeneous, due to the fact that the aperture is built according to the Helmholtz set-up. The circular coils are positioned in parallel on one axis. The distance between the coils is half the coil diameter. The transponder is positioned in the middle of the coil axis.

Determination of the minimum powering field strength is possible by changing the field strength through increasing the coil current. The relation between the generated magnetic flux / field strength and coil current can either be measured with a calibrated field probe, or calculated as follows:

$$(2) \qquad B = \frac{4}{5} \cdot \sqrt{\frac{4}{5}} \cdot \frac{m_o \cdot m_r \cdot N \cdot I}{d/2} = m_0 \cdot m_r \cdot H$$

B: magnetic flux (Tesla=Wb/m2)
H: magnetic field strength (A/m)
N: Number of Helmholtz Coil windings
d: Coil diameter (m)
I: Coil current (A)
μ_o: magnetic field constant (Vs/Am) = 4×p×10 $^{-7}$ Vs/Am
μ_r: relative magnetic field constant (in air: =1)

The Helmholtz set-up can be used for the specification of transponders in the temperature range from -40 to +85 ºC. Tests showed, however, that deviations of the field strength caused by temperature are negligible.

The data telegram of the transponder can be captured by a pick-up coil (for example: 10 windings, thin wire to minimize influence) which wraps the transponder. The pulse modulated signal can be adjusted at the signal generator. The measurement of the power pulse and transponder diagram can be done with the help of an oscilloscope triggered by the generator signal (see Figure 19). As soon as a data telegram is completely detected the minimum necessary field strength (calculated with equation 2) can be monitored.

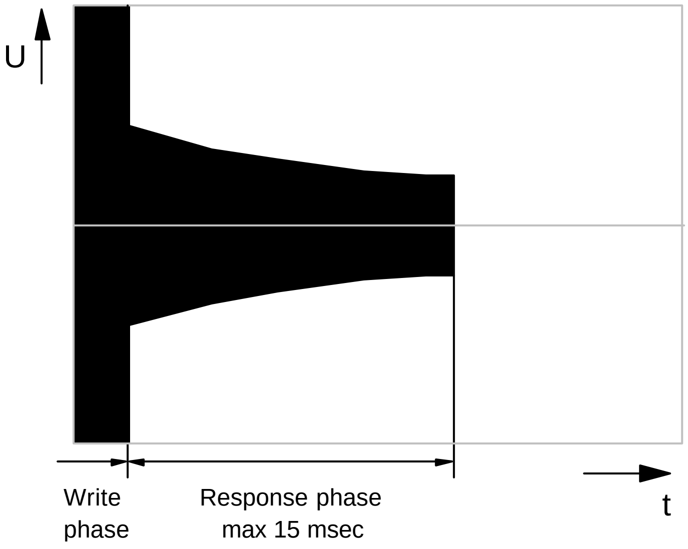


Figure 20: Received signal at the pick up coil, if power field strength is sufficient

9.3 Measurement Set-Up: Transponder Signal Strength

The transponder has to be located into a homogeneous field (Helmholtz set-up). The pulsed power signal is generated by a signal generator. A calibrated field strength probe picks up the transponder signal. The field strength can be calculated by using the calibration factor of the field strength probe.

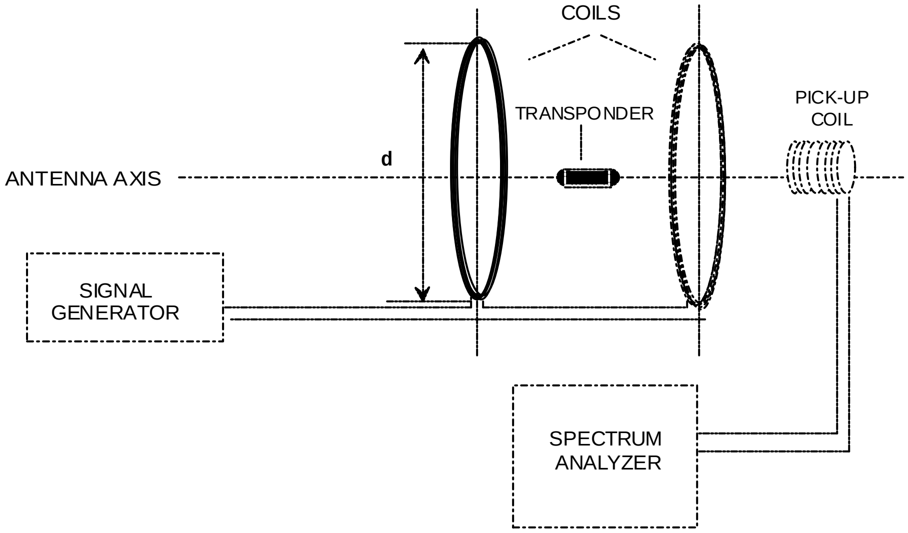


Figure 21: Determination of the transponder signal strength (data transmission signal strength) with Helmholtz aperture

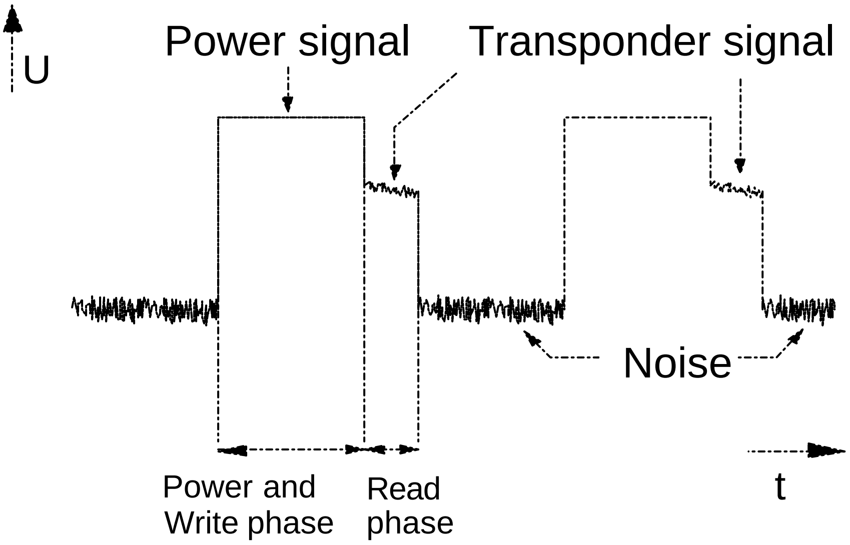


Figure 22: Monitored signal voltage at the spectrum analyzer (time domain mode)

10. Specifications

10.1 Absolute Maximum Ratings

All data given for free air operating temperature range (unless otherwise noted).

PARAMETER		CONDITION	MIN.	NOM.	MAX.	UNIT
Operating temperature (read)	$T_{a\,read}$		-40		85	^{o}C
Operating temperature (program)	$T_{a\,Prog}$		-40		85	^{o}C
Storage temperature	T_S		-40		100	^{o}C
Storage temperature	T_S	5 min			175	^{o}C
Field strength	H_{exc}	134.2 kHz			168	dBμA /m

10.2 Recommended Operating Conditions

All data given for free air operating temperature range, a charge time of 50 ms, and a transmitter frequency of 134.2 kHz ± 40 Hz (unless otherwise noted).

PARAMETER	SIGN	NOTE	MIN	NOM	MAX	UNIT
Transmitter frequency	fTX		134.16	134.2	134.24	kHz
Charge Time	tTX		15	50		ms
Write Low Bit Duration	tbitL		0.45			ms
Write High Bit Duration	tbitH		0.95			ms
Write Pulse Pause/ Low Bit	toffL	RI-RFM-006A-00 (Note 1)	0.1	0.12	0.14	ms
Write Pulse Pause/ High Bit	toffH	RI-RFM-006A-00 (Note 1)	0.46	0.48	0.5	ms
Programming Time	tprog		15			ms
Programming Activation Fieldstrength	Hprog	-40 to 85C	140.5 *			dBμA/m
Programming Activation Fieldstrength	Hprog	@25C	137.5 *			dBμA/m
Activation Fieldstrength	Hact	-40 to 85C	136.5 *			dBμA/m
Activation Fieldstrength	Hact	@25C	132.5 *			dBμA/m
Encryption Time	tenc		4	6		ms
Read Time	tRD			15		ms

* = Preliminary

Note 1: *Recommendations are only valid for RI-RFM-006A-00 [1] used in a low quality factor key lock application with tapped antenna coil circuitry [2]. Use of other RF Module circuitries and/or reader antennas might result in minor adaption of the write timing.*

10.3 Characteristics

All data given for free air operating temperature range, a charge time of 50 ms, and a transmitter frequency of 134.2 kHz ± 40 Hz (unless otherwise noted).

PARAMETER		CONDITION	MIN.	NOM.	MAX.	UNIT
Operating quality factor	Qop	Note 1	62			
Allowed Q-factor drop	Qdrop				-3	
Low bit transmit frequency	f_L		131.5		139.0	kHz
Low bit transmit frequency	f_L	+ 25 °C	132.2	134.3	136.2	kHz
Low bit duration	t_L		0.117	0.119	0.121	ms
High bit transmit frequency	f_H		120.0		128.0	kHz
High bit transmit frequency	f_H	+ 25 °C	121.0	122.9	125.0	kHz
High bit duration	t_H		0.128	0.130	0.132	ms
Write High bit detection threshold time	$t_H$det			$48 \div f_L$		
Transponder output field strength @ 5 cm	H_{out}		80.5		102.5	dBµA/m
FSK Modulation index (read); f_L - f_H	m_{read}	+ 25 °C		11		kHz
FSK Modulation index (read); f_L - f_H	m_{read}		9		15	kHz
Data transmission rate (read)	r_{read}		7.5		8.7	kbit/s
Data transmission time (read)	t_{read}		13		15	ms
ASK modulation index (write)	m_{write}			100		%
Data transmission rate, high bits (write)	r_{write}	Note 2		1		kbit/s
Data transmission rate, low bits (write)	r_{write}	Note 2		2		kbit/s
Data transmission time	t_{write}	Note 3		36		ms
Encryption execution time	t_{encx}			3		ms

Note 1: *Specified Qop must be met in the application over the required temperature range. Refer to the test set-up shown in figure 17.*

Note 2: *Adaptable to application.*

Note 3: *Encryption Mode.*

10.4 Environmental Data and Reliability

PARAMETER		CONDITIONS	MIN.	NOM.	MAX.	UNIT
Programming cycles	Note 1	25 ^{o}C	10k			cycles
Data retention time	Note 1	10k cycles @ 25^{o}C storage temperature	10			years
EM Radiation immunity		1...512 MHz	100			V/m
EM Radiation immunity		512..1000MHz	50			V/m
ESD Immunity	IEC 801-2		2			kV
X-ray dose					2000	RAD
Vibration (Note 2)	IEC 68-2-6, Test Fc					
Shock	IEC 68-2-27, Test Ea					

Note 1: *Cumulative failure rate 1%.*

Note 2: *f = 10 - 2000 Hz.*

10.5 Memory

PARAMETER	DATA
Memory size	88 bits
Memory organization	4 pages
Identification data	8 bits R/W 32 bits RO

10.6 Package

PARAMETER	DATA
Dimensions	23.1 mm x 3.85 mm diameter (see figure 3)
Weight	0.6 g

Appendix A: Conversion Formula

Conversion formula between magnetic flux, magnetic field strength and electric field strength.

$$B = m_0 \cdot H$$
$$E = Z_F \cdot H$$

$$\mathrm{H} = \left[\frac{\mathrm{E}}{\mathrm{dB}\mathit{m}\mathrm{V / m}} - 51.5\right]\frac{\mathrm{dB}\mathit{m}\mathrm{A}}{\mathrm{m}} \qquad ; \qquad \lfloor \mathrm{H} \rfloor = \frac{\mathrm{dB}\mathit{m}\mathrm{A}}{\mathrm{m}} \qquad ; \qquad \lfloor \mathrm{E} \rfloor = \frac{\mathrm{dB}\mathit{m}\mathrm{V}}{\mathrm{m}}$$

B = magnetic flux [Tesla = Wb/m^2 =Vs/m^2]; 1 mWb/m^2 = 0.795 A/m

H = magnetic field strength [A/m or in logarithmic term dBμA/m]

E = electrical field strength [V/m or in logarithmic term dBμV/m]

μ_0 = magnetic field constant = 1.257×10^{-6} Vs/Am

Z_F = free space impedance = 120 π Ω = 377 Ω